

## MAKING FOAM GLASS BASED ON NATURAL AND TECHNOGENIC ALUMINOSILICATES

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It is shown that aluminosilicate rocks and materials can be used to make glass suitable for making foam glass. Characteristic moduli are proposed for evaluating the suitability of aluminosilicate materials for glassmaking and for the glass obtained. The batch compositions for making glass and foam glass are presented.

**Key words:** foam glass, aluminosilicate rock, raw material, glassmaking, batch composition, viscosity and surface tension of glass, foaming time, glass phase, crystalline phase, pore structure.

As result of its particular geographic location and severe climate Russia is forced to expend enormous amounts of energy on heat buildings and various structures. The energy problem is also associated with the low quality and limited assortment of materials used for heat insulation of heat-generating facilities, heat supply lines, and heat-generation plants.

Of all known heat insulation materials the most desirable for use in Russia is foam glass — a material possessing a combination of unique operational properties satisfying the most stringent normative requirements.

The particulars of foam-glass technology predetermine the quite high cost of foam glass, but ultimately the long service life of foam glass greatly increases its cost-effectiveness [1].

Cullet, especially sheet-glass cullet, is very advantageous to use in the production of foam glass, but large amounts of cullet are required because of the large production volume of foam glass. In addition, in recent years glass works have been striving to use as much cullet as possible as a recycled raw material in order to conserve material and energy resources used for manufacturing the primary products. Focusing on container-glass cullet, the fact that glass with variable chemical composition enters the process and questions concerning collection of the glass and removing different organic and inorganic impurities from it must be taken into account.

In 2000 a 10,000 m<sup>3</sup>/yr process line for manufacturing foam glass was assembled and put into operation at the Tomsk Home Building Works (HBW) with the direct partici-

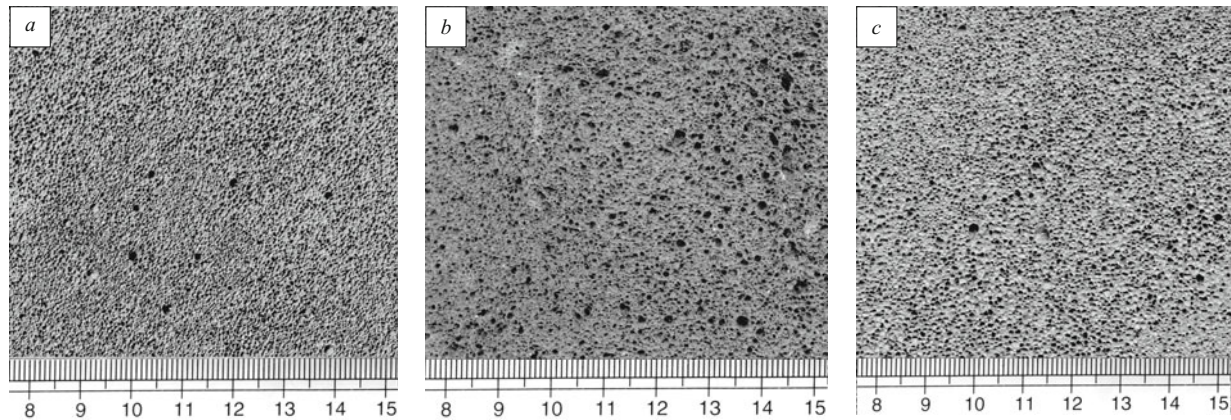
pation of the present author [2, 3]. The initial material consisted of cullet from the Tomsk Lamp-Glass works and a carbon foaming agent (coke nuts). Experience in producing foam glass based on lamp-glass cullet (2000 rubles/ton) showed that its use in the production of 450 × 450 × 100 mm foam-glass blocks with density 175 – 200 kg/m<sup>3</sup> and production cost 1500 rubles/m<sup>3</sup> is very efficient. The general appearance of the porous structure of foam-glass blocks is displayed in Fig. 1a.

Economic problems have made it impossible to produce foam-glass blocks. Since 2004, after foaming furnaces were rebuilt, the workshop began to produce foam crumb, which the Works uses for its own needs in the production of various fills. In 2010, because of the building crisis the production of foam crumb was stopped but it can be restarted at any time.

The transition to the production of energy-conserving and LED lamps makes it possible to reduce the production of incandescent lamps, which will sharply decrease the volume of glass scrap produced and the problems with the initial material for foam-crumb manufacturers. The latter is graphic confirmation of the need to organize a glassmaking division at every foam-glass production plant.

Analysis of the technological particulars of obtaining foam glass with a carbon gas-generating agent shows that foam glass can be obtained not only from glass made using conventional batches and the classical technology, including fining and homogenization stages, but also using batches containing different aluminosilicate rocks (ASR). Scientific articles on the problems of obtaining foam glass give examples of using aluminosilicate rocks and obtaining foam glass by combining the silicate and glass formation processes with the foaming process [4]. The implementation of this method is very attractive, but it is difficult to call the product so ob-

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**Fig. 1.** Character of the porous structure of foam glass obtained (*a*) from lamp-glass, (*b*) on the basis of loam, and (*c*) on the basis of zeolite rock.

tained a foam glass, since its porous structure is extremely nonuniform with pores to 5 – 10 mm in size predominating.

We believe that the following sequence of technological steps must be maintained in order to obtain foam glass: glassmaking → rapid cooling of the glass and obtaining glass crumb → grinding the glass and preparing the foam-glass batch → foaming the batch → firing the foam-glass blocks. The molten glass obtained using aluminosilicate rock must be cooled rapidly to prevent the glass, which contains elevated amounts of aluminum oxide and iron oxide, from crystallizing.

The use of ASR to make glass will greatly expand the raw materials base of foam-glass production. For this reason,

a study was made of the possibility and particulars of making glass based on such rocks and the suitability of such glass for making foam glass [5]. Clays, loams, shales, burnt rock, acidic ashes from heat-and-power plants, zeolite rock, and granite rocks served as objects of study. A comparative assessment of the suitability of these rocks for glassmaking was made with respect to the content of silicon oxide and aluminum oxide (alumina modulus  $\Gamma = \text{SiO}_2/\text{Al}_2\text{O}_3$ ) and with respect to the silicate modulus  $n = \text{SiO}_2/(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$ . The values of these moduli for some ASR are presented in Table 1, which shows that the alumina modulus fluctuates in the range  $\Gamma = 2.66 - 5.79$ , while the silicate modulus  $n = 1.26 - 5.58$ .

**TABLE 1.** Chemical Composition of Aluminosilicate Rock

Aluminosilicate rock	Content, wt. %								Moduli	
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	R <sub>2</sub> O	other	Σ	SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> /(Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> )
Zeolite rock	68.31	12.06	0.86	2.88	1.03	2.67	11.69	99.50	5.66	5.28
Loams	69.40	13.19	3.35	2.03	0.67	4.68	5.47	98.79	5.26	4.19
Shales-1	63.39	14.01	10.40	0.78	0.98	6.62	3.80	99.98	4.52	2.59
Shales-2	67.14	15.30	5.87	2.21	2.09	0.43	4.92	97.96	4.39	3.17
Diatomite-1	68.45	13.34	2.83	3.08	2.48	—	6.75	96.93	5.13	4.23
Diatomite-2	92.02	4.64	2.37	0.75	0.08	0.24	—	100.10	19.83	13.12
Clay	69.08	16.29	5.25	3.84	3.22	2.33	—	100.01	4.24	3.20
Perlite	76.00	13.11	1.22	2.16	2.10	5.41	—	100.00	5.79	5.30
Basalt	52.10	15.07	10.43	10.42	6.56	3.11	1.20	98.89	3.45	2.04
Diabase	46.32	15.08	13.11	8.61	9.80	2.42	2.90	98.24	3.07	1.64
Granite	75.54	16.77	3.29	2.08	1.64	1.18	0.50	101.00	4.50	3.76
Ash from heat-and-power plant-1	65.20	18.21	5.97	5.51	0.38	—	4.03	99.72	3.58	2.45
Ash from heat-and-power plant-2	59.20	22.21	7.97	5.28	0.42	—	4.31	99.81	2.66	1.96
Tripoli	75.40	9.05	4.47	1.26	0.80	—	6.17	97.15	8.33	5.58
Natural burnt clays	67.80	19.53	5.57	3.25	1.53	—	1.23	98.91	3.47	2.70

**TABLE 2.** Chemical Composition of Rocks and the Glass Based on Them

Material	Content, wt. %									Moduli	
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	other	Σ	SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub> /(Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> )
Zeolite rock	64.80	13.26	2.46	2.50	1.84	0.63	3.20	11.20	99.89	4.88	4.12
Zeolite and dolomite based glass	59.30	10.61	3.65	4.29	3.69	16.27	2.52	—	100.33	5.59	4.16
Zeolite and lime based glass	58.82	10.53	3.62	6.14	1.78	17.13	2.50	—	100.52	5.59	4.16
Burnt rock	67.80	19.53	5.57	3.25	2.05	—	—	1.23	99.43	3.47	2.70
Burnt rock based glass	57.66	14.53	4.25	4.56	3.60	15.68	—	—	100.28	3.97	3.07
Loam	64.78	13.00	4.76	4.95	1.00	2.00	1.27	7.98	99.74	4.98	3.65
Loam based glass	57.85	10.15	3.83	6.07	2.95	17.90	0.97	—	99.72	5.70	4.14
Ash from heat-and-power plants	65.20	18.21	5.97	5.51	0.38	—	—	4.03	99.72	3.58	2.45
Ash based glass	56.72	13.80	4.63	6.34	2.41	15.96	—	—	99.86	4.11	3.07
Granite rock	63.22	19.14	—	2.80	2.04	3.16	9.60	—	99.96	3.30	3.30
Granite based glass	55.51	13.73	0.25	4.03	3.51	16.16	6.97	—	99.98	4.04	3.97

Rocks with high silica content are exceptions. But silicate glass can be made from these rocks with appropriate additions to the batch.

When glass batch was made on the basis of ASR, the composition of the mixture of the aluminosilicate component and soda was adjusted in accordance with the calculations by additions of quartz sand, dolomite, or lime. The component composition of the prepared batches was as follows: 62–64%<sup>2</sup> ASR, 20–22% carbonate of soda, 7–10% quartz sand, and 7–8% lime or dolomite. The components were carefully mixed and additionally comminuted in laboratory edge-runner mills to complete passage through a 0.5 mm cell sieve. The ready batch was loaded into refractory metallic molds, heated in a muffle furnace to 970°C, and soaked at this temperature for 1.5 h until gas-release ceased. The formed glass contained a large number of fine gas inclusions 0.1–0.5 mm in size and exhibited indications of crystallization. The chemical composition of glass made using loam, zeolite rock, burnt rock, granite rock, and ash from heat-and-power plants and the moduli are presented in Table 2.

Next, the glass was rapidly cooled in water, extracted from the mold, and comminuted together with 3–4% coke nuts and 1% sodium or potassium nitrate (increase of the oxidation potential of the batch) to specific surface area 600 m<sup>2</sup>/kg.

It should be noted that when this process is implemented under industrial conditions glassmaking can be conducted either by sintering at 950°C using refractory dusting powders (clay, ash, diatomite, tripoli, opoka) or by melting at temperatures 1100–1200°C, at which the viscosity of the molten glass decreases considerably and the dissolution of quartz grains and glass formation intensify. Small-size glassmaking furnaces with direct electric or combined heating should be

used in this case. Small-size cupola furnaces, which are used to make mineral cotton, can also be used. It is best to use granulated or briquetted glass batch in these units.

The required amount of foam-glass batch obtained ( $m = \rho V$ , where  $m$  is the mass of the batch loaded,  $\rho$  is the prescribed density of the foam glass, and  $V$  is the volume of the mold), was loaded into heat-resistant metallic molds, which were placed into a furnace with temperature 800°C, where they soaked for 60–70 min. After the batch was foamed, the mold with the foam glass was removed from the furnace and allowed to cool in air for 2 min, and then placed in a different muffle furnace, preheated to 650°C, to stabilize and subsequently cool together with the furnace.

The porization of the foam-glass batch occurs in two stages. At the first stage the batch densifies and sinters with gas-impermeable glass skin being formed. At the second stage the glass sinter foams directly. The duration of the foaming process is predetermined by the rate of formation of the new surface  $v$  (m/sec), which can be determined from the relation

$$v = \sigma/\eta, \quad (1)$$

where  $\sigma$  is the surface tension of the glass (mJ/m<sup>2</sup>) and  $\eta$  is the viscosity of the glass at the foaming temperature (Pa · sec).

The foaming time of the batch can be determined from the known quantity  $v$  using the relation

$$\tau_f = \frac{\sqrt[3]{V_f} \rho_{gl}}{60v \rho_{fg}}, \quad (2)$$

where  $\tau_f$  is the computed foaming time of the batch (min),  $V_f$  is the volume of the gas phase in the foam glass with the prescribed density (m<sup>3</sup>),  $\rho_{gl}$  is the true density of the glass

<sup>2</sup> Here and below the content by weight.

(kg/m<sup>3</sup>),  $\rho_{gl} = 2500 \text{ kg/m}^3$ ,  $\rho_{fg}$  is the density of the foam glass (kg/m<sup>3</sup>), and

$$V_f = 1 - \frac{\rho_{fg}}{\rho_{gl}}.$$

We shall show that the relation (2) is applicable for glass based on loam and foam glass with density 180 and 200 kg/m<sup>3</sup>. According to [6], the temperature of the transition of this glass into a liquid state with viscosity  $10^8 \text{ Pa} \cdot \text{sec}$ , determined from M. V. Okhotin's relation, is 667°C. The surface tension of the glass, as calculated by A. A. Appen [7], is  $343 \times 10^{-3} \text{ J/m}^2$ . The formation rate of the new surface is  $v = 3.43 \times 10^{-3} \text{ m/sec}$ . The foaming time of foam glass for density 180 kg/m<sup>3</sup> is

$$\tau_f = \frac{\sqrt[3]{0.928}}{60 \times 3.43 \times 10^{-3}} \times \frac{2500}{180} = 65.8 \text{ min},$$

while for density 200 kg/m<sup>3</sup>

$$\tau_f = \frac{\sqrt[3]{0.920}}{60 \times 3.43 \times 10^{-3}} \times \frac{2500}{200} = 59.1 \text{ min}.$$

The computed values of the foaming time of the batch are in good agreement with the experimental data. It should be noted that the surface tension of the glass predetermines the number of gas pores formed per unit volume of the foam glass. As the surface tension of the glass decreases, the number of gas pores increases, the size of pores decreases, and the formation rate of the new surface decreases.

The thickness of the interpore barriers and the configuration of the gas pores formed (rounded or polyhedral) depend on the viscosity of the glass and the foaming temperature of the batch. For this reason, foaming must be conducted at constant temperature, since, for example, as temperature increases, the viscosity of the glass decreases, the formation rate of the new surface increases, and the foaming time decreases. Therefore, for a prescribed foaming time (velocity of the molds in the furnace) a foam glass structure with an extremely nonuniform pore-size distribution can form.

Figure 1 shows the structure of foam glass obtained on the process line at the Tomsk HBW from lamp-glass (a), loam-based foam glass (b), and zeolite rock (c) under laboratory conditions.

#### ASR-Based Foam Glass

Compression strength, MPa . . . . .	1.0 – 1.4
Density, kg/m <sup>3</sup> . . . . .	180 – 200
Thermal conductivity, W/(m · K). . . . .	0.058 – 0.065
Water absorption, vol.% . . . . .	3 – 5
Predominate pore size, mm. . . . .	0.5 – 3

The high strength of foam glass based on aluminosilicate glass is explained by the presence of glass in the initial powder and a crystal phase (8 – 14%) in the interpore barriers of the foam glass. The crystal phase is represented by the following: quartz (0.411, 0.370, 0.334, 0.245, 0.228, 0.212, 0.197, 0.154 nm), albite (0.411, 0.370, 0.321, 0.295, 0.255, 0.244, 0.231, 0.212, 0.201, 0.189, 0.182 nm), and anortite (0.408, 0.320, 0.295, 0.251, 0.213, 0.183, 0.162 nm).

It should be noted that x-ray analysis shows the foam-glass samples to be more highly crystallized than the initial crystal. This attests that conditions adequate for the development of crystallization processes are created during foaming of foam-glass batch.

These studies show confirm that it is best to use aluminosilicate rock and materials as the initial material for making a glass which can serve as a basis for obtaining foam glass with lower energy consumption. The availability of a stable source of glass will make it possible to bring cullet from different silicate glasses into the production of foam glass and to introduce up to 50% cullet into the foam-glass batch.

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